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25K HALVORSEN LOADER AUTOMATION REPORT

Eduardo Nieto

Airbase Technologies Division
Air Force Research Laboratory
139 Barnes Drive, Suite 2
Tyndall AFB, FL 32403-5323

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EDUARDO NIETO, 1st Lt, USAF
Work Unit Manager

WALTZ.WALTER.M.1006453097
Digitally signed by WALTZ.WALTER.M.1006453097
DN: c=US, o=U.S. Government, ou=DoD, ou=PKI, ou=USAF, cn=WALTZ.WALTER.M.1006453097
Date: 2013.01.03 08:25:52 -06'00'

WALTER M. WALTZ, DR-III
Program Manager

RHODES.ALBERT.N.III.1175488622
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ALBERT N. RHODES, PhD
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14. ABSTRACT
The Air Force Research Laboratory Airbase Technologies Division (AFRL/RXQ) researched robotic technologies to support flightline operations with the goal of improving the efficiency and safety in deployed locations. From February to October 2012, the Robotics Team designed and implemented a robotic control package for autonomous driving of the 25K Halvorsen Loader system. This project focused on robotic technologies for the cargo loader (K-Loader) systems that automate the transportation and handling of palletized cargo between the loading ramps and aircraft. This project was enabled by AFRL/RXQ's extensive repository of autonomous ground vehicle driving behaviors that were adapted to the K-Loader systems including: waypoint driving, obstacle avoidance, traversability grid mapping, and dynamic path planning. On October 25th, AFRL/RXQ conducted a successful demonstration of phase I of the Automated K-Loader system, which concluded the funded work for this effort.

15. SUBJECT TERMS
aircraft loader, tele-operated, automated, autonomous driving, remote controlled, robotic control package

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. SUMMARY

The Air Force Research Laboratory Airbase Technologies Division (AFRL/RXQ) researched robotic technologies to support flightline operations with the goal of improving the efficiency and safety in deployed locations. From February to October 2012, the Robotics Team designed and implemented a robotic control package for autonomous driving of the 25K Halvorsen Loader system. This project focused on robotic technologies for the cargo loader (K-Loader) systems that automate the transportation and handling of palletized cargo between the loading ramps and aircraft. This project was enabled by AFRL/RXQ's extensive repository of autonomous ground vehicle driving behaviors that were adapted to the K-Loader systems including: waypoint driving, obstacle avoidance, traversability grid mapping, and dynamic path planning. On 25 October 2012, AFRL/RXQ conducted a successful demonstration of Phase 1 of the Automated K-Loader system, which concluded the funded work for this effort.

2. INTRODUCTION

2.1. Report Scope

This report serves as a summation of Phase 1 of the Automated 25K Halvorsen Loader project and details about final demonstration. It includes details on various technologies, robotic automation procedures, and test events for this project.

2.2. Project Scope

The purpose of this effort was to develop and demonstrate flexible autonomous technologies for the K-Loader system in order to automate the handling of palletized cargo between the loading ramps and aircraft. Air Force Research Laboratory (AFRL) proposed to conduct this research in four phases with this project addressing Phase 1, the automation of the K-Loader's tasks. The unmanned system was tested by performing all the loader functions to include driving, pallet handling, and raising/lowering the vehicle's deck.

2.3. Background

The primary United States Air Force (USAF) customer for these technologies is Air Mobility Command (AMC). AMC took the lead in describing automated systems as a potential material solution to their need for better cargo handling systems. AFRL/RXQ coordinated with AMC Headquarters (HQ) to secure an asset and support for the proposed technology developments. This resulted in the temporary transfer of an E936 Halvorsen 25K Loader to AFRL/RXQ, Tyndall Air Force Base (AFB) to support this project. The AMC/A4TR CMD MGR, Aerial Port Equipment, supported this project by obtaining approval from Warner-Robbins Air Logistics Center for AFRL to perform the proposed modifications to the E396 Halvorsen 25K Loader on loan to AFRL.

Autonomous systems technologies have advanced to a point that it is feasible to investigate their use for a wide variety of critical Air Force missions. Autonomous systems have great potential to improve the efficiency of airbase operations and increase personnel safety. This is especially true in deployed and contested environments where traditionally safe rear areas are now vulnerable to attack from non-conventional forces with small arms. Missions that require personnel to be exposed to attack while performing repetitive tasks are ideal for the introduction of unmanned and autonomous systems.

Cargo transportation, aircraft fueling, and munitions handling are just a few missions that have repetitive tasks that can be improved by the introduction of autonomous system technologies. AMC lists automated cargo handling as one of its critical capability gaps, and expressed strong interest in technologies that automate the cargo handling process. One of the Air Mobility Master Plan 2010's [1] potential solutions is autonomous loading and unloading. The Air Force developed and refined highly specialized K-Loader systems that transport and load palletized cargo very efficiently in the aerial port environment. The opportunity for improvement in these operations is not in making a better K-Loader system; it is in automating the repetitive tasks that the loader performs.

AMC identified deficiency Number: 04-AL-036 - Offloads Without Materials Handling Equipment (MHE) as part of the Airlift Roadmap for the AMC 2010 Master Plan [1]. This is stated as “The Mobility Air Force (MAF) needs the ability to rapidly offload and onload all types of equipment and personnel at austere airfields with no organic support capability.” Their solution is “to ensure we have the capability to offload and onload all types of equipment and personnel at austere airfields with no organic support capability, we need to pursue technology that will provide us with true autonomous loading and unloading.” [1] This research project was the first step in addressing this capability gap. The technologies developed as part of this project will directly lead to systems that will meet this AMC deficiency and support their identified solution.

2.4. Objectives

AFRL/RXQ studied and developed autonomous systems technologies in support of aerial port operations. An opportunity exists to greatly improve the efficiency and safety of current operations by introducing autonomous technologies. This project proposed to develop and demonstrate flexible autonomous technologies for the K-Loader system in order to automate the handling of palletized cargo between the loading ramps and aircraft. AFRL/RXQ proposed to conduct this research in four phases:

- Phase 1—K-Loader automation tasks
- Phase 2—Terminal interface automation tasks
- Phase 3—Aircraft interface automation tasks
- Phase 4—Experimental demonstration in an operationally representative environment.

This report only focuses on the objectives and accomplishments of the first phase, due to the funding of only Phase 1. If the effort continues to the next phases other reports will be written with more detail about the objectives of those phases.

The objective of Phase 1 was to design and implement an autonomous control package for the K-Loader system. The plan was to build upon the body of work that exists for vehicle automation and autonomous driving to accomplish this task. AFRL/RXQ Robotics Team developed an extensive repository of autonomous ground vehicle driving behaviors that were adapted to the K-Loader systems including: waypoint driving, obstacle detection/avoidance, traversability grid mapping, and dynamic path planning. Leveraging this work allowed this phase to focus on automating the unique capabilities of the K-Loader system. The results of this study was used in designing and implementing system modifications (computer control, sensors, actuators, etc) that allowed autonomous behaviors to control and monitor the state of the system as well as its environment.

Phase 2 is focused on the cargo terminal interface automation tasks. There are many examples of autonomous systems (air, ground, and sea) performing advanced mobility in a wide variety of environments, but these systems do not interact physically with other dynamic objects. The main purpose of the K-Loader is to transport and load cargo by purposefully coming into physical contact with other objects (loading ramps, aircraft, and cargo pallets). This phase will develop the autonomous behaviors to control: approaching and departing terminal, loading standard 463L pallets, securing the cargo, and monitoring the cargo during travel. This approach will use fused

sensor data and robust decision making techniques to provide the controls for the system operations. Special consideration will be given to working with uncertain and possibly erroneous/degraded data from the systems sensors.

Phase 3 will concentrate on the aircraft interface automation tasks. This phase will build upon the technologies developed for the terminal interface automation tasks. The primary difference will be the precision and coordination required to ensure that no damage occurs to the cargo or aircraft during these operations. Research will be conducted to determine the appropriate sensors and operating modes with special attention paid to automated material handling systems that require similar levels of precision (automotive, machining, computer chip manufacturing systems). Flexible autonomy techniques will be implemented for these operations as coordination with the aircraft loadmaster(s) will be critical to successfully transfer cargo between the K-Loader and aircraft.

Phase 4 will conduct a series of operational experiments to characterize the system performance handling palletized cargo between the loading ramps and aircraft. These experiments will be planned for a mock up or decommissioned aircraft in a controlled environment (closed or simulated airfield). This is due to the high potential cost of damage to an operational aircraft. If the experiment series proves successful, a demonstration of the system with an operational aircraft will be pursued. If this phase is funded a final report will be written, presentation of the results will be presented to AMC, and the technology transfer process will be started. Transfer activities would include delivering the system for user evaluation in an operational environment.

3. METHODS, ASSUMPTIONS, AND PROCEDURES

3.1. Concept of Operations

AFRL/RXQ researched robotic technologies to support flightline operations with the goal of improving the efficiency and safety in deployed locations. In a 6 month period, from February to October 2012, the Robotics Team designed and implemented a robotic control package for autonomous driving of the 25K-Halvorsen Loader system. The current funding for the project allowed the team to focus on the first phase. Phase 1 focused on robotic technologies that automate the transportation and handling of palletized cargo between the loading ramps and aircraft. The Robotics Team decided to include some terminal interface automation capabilities (Phase 2) using the sensors on board. Because of the early termination of this project, due to AFRL's divestment of the RXQ division, many objectives from Phase 1 and 2 were accelerated.

The project successfully demonstrated safe manual operation and tele-remote operation of all the K-Loader functions, tele-remote operation driving, and waypoint driving. In addition, the system demonstrated the loading of cargo on/off the K-Loader into a simulated loading ramp.

3.1.1. K-Loader System Integration

The remote control system for a vehicle is comprised of AFRL/RXQ standard modules, a vehicle interface module (VIM), the power distribution module (PDM), the vehicle command module (VCM), an operator control station (OCS), a Video Module, and a Navigation Sensor Module (NSM) employing Global Positioning System (GPS) and inertial measurement unit (IMU). These modules are designed so that they are interoperable with other vehicles. These individual modules are designed to be independent from each other. The modules are ideally installed on a vehicle in one central location for them to interface with each other. Due to the design of the K-Loader and limited space constraints, the modules were located in different locations.

3.1.1.1. Vehicle Interface Module

The K-Loader's direct control of vehicle functions are at the distribution box (D-Box) and main panel box in the form of relays, switches, and fuses. In order to automate the K-Loader, an electronic control interface system was installed. AFRL/RXQ integrated a TT-Controller (TTC) system that ties directly into relays and switches of the vehicle and provides a controller area network (CAN) message interface for the other modules to communicate. The HY-TTC 200 is a programmable electronic control unit for sensor and actuator management. The TTC was used to configure all the input/output (I/O) for all the switches and relays in the K-Loader. The robust aluminum diecast housing shields it from electromagnetic disturbance and mechanical stress. The VIM is located in the D-Box and main panel (Figure 1).

3.1.1.2. Power Distribution Module

The PDM is simply a power hub for distribution of power to the individual modules of the remote control system. The outputs of the PDM are capacitor backed up to provide stable power output during engine cranking and other high current draw conditions that the vehicle may encounter which would affect the sensitive remote system modules. Most of this module is located in the UnderCab plate (Figure 1).

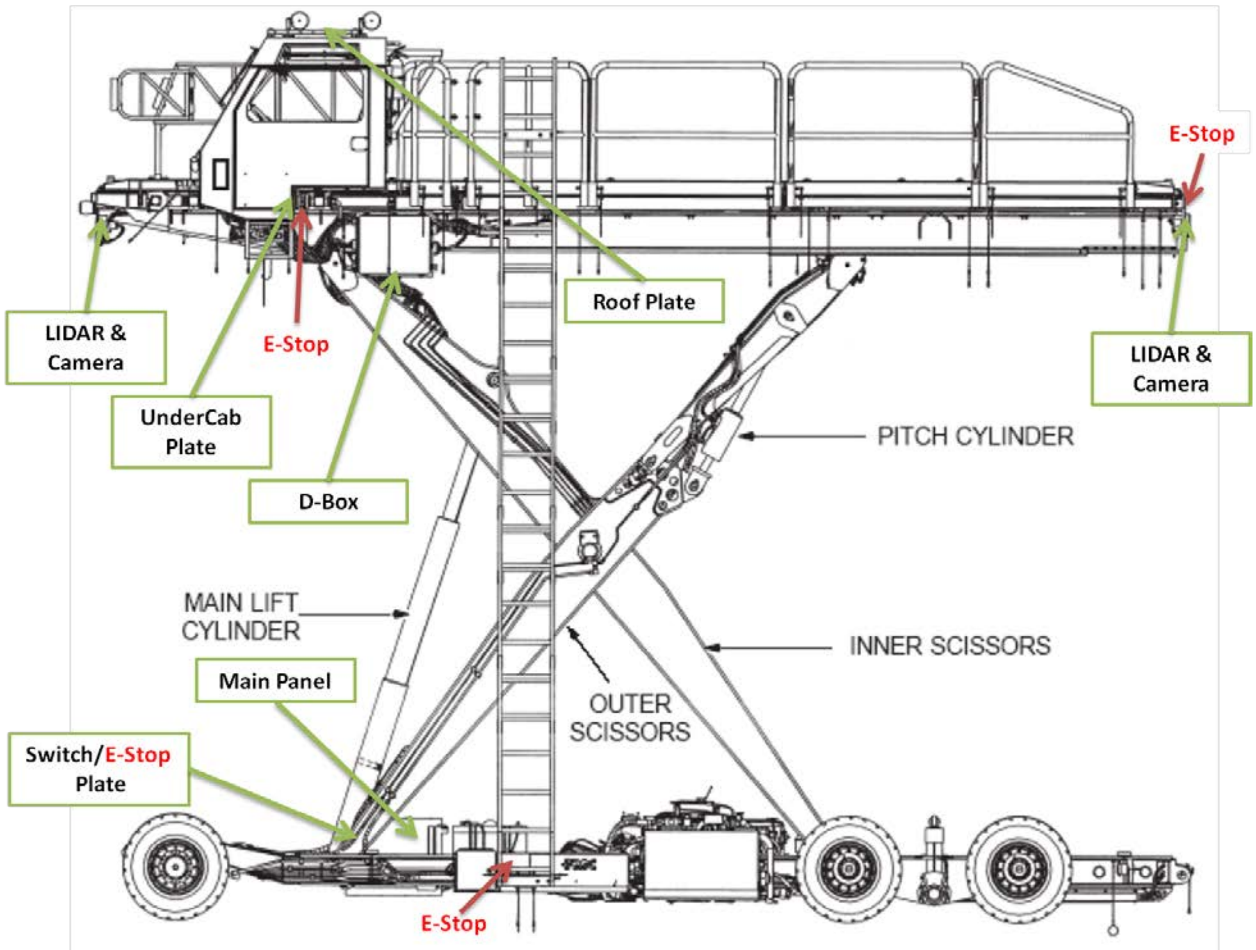

Figure 1. K-Loader Systems Integration

3.1.1.3. Vehicle Command Module

AFRL/RXQ's VCM is the interface between the operator and the vehicle via a control radio. The VCM has the necessary programming to drive the vehicle semi-autonomously or pass along the remote operator's driving commands. This module uses the input of the NSM to achieve exact driving control during autonomous operation, and sends the vehicle location information back to the OCS in tele-operated mode for operator reference. The video module also transmits video data through the VCM as it is the interface to the OCS. The non-standard VIM commands and vehicle status are also passed through this module. The VCM is located on the roof plate (Figure 1).

3.1.1.4. Navigation Sensor Module

AFRL/RXQ's standard NSM is capable of taking differentially-corrected GPS and integrating it with the output of the inertial measurement unit through a Kalman filter to provide the precise velocity, attitude, and position of the vehicle. The NSM is located on the Roof Plate (Figure 1). AFRL/RXQ's standard GPS base station provides the differential corrections needed by the NSM for accurate positioning of the vehicle.

3.1.1.5. Video Module

AFRL/RXQ's standard video module takes the inputs of up to 8 cameras (any combination up to 4 pan-tilt-zoom and 4 fixed). These cameras are connected to an internal multiplexer and the video is sent to a frame grabber for digitization and transmission back to the OCS. This module can provide either one or two channels of streaming video. For the K-Loader three channels of video are sent back to the OCS, two fixed cameras, one in the front and one in the back (Figure 1), and one on the roof (Figure 1) to provide a 360° view of the area surrounding the vehicle. The camera view being streamed back to the OCS is selectable with the operator control unit (OCU).

The UnderCab systems plate (Figure 2) includes a low-level computer, GPS receiver, two Ethernet switches, and an emergency-stop (E-Stop).

Figure 2. UnderCab Systems Plate

The main panel systems plate (Figure 3 and Figure 4) includes a TTC, relays, fuses, and switches.

Figure 3. Main Panel Systems Plate - TTC

Figure 4. Main Panel Systems Plate - Fuses and Relays

Outside of the Main Panel a plate was installed with two switches (Figure 5 and Figure 6) to select the operation mode, tele-remote operated or manual operated, a service Ethernet port, and an E-Stop.

Figure 5. Operation Mode Switches (Front View)

Figure 6. Operation Mode Switches (Angle View)

The D-Box systems plate (Figure 7) includes another TTC, relays, switches, and a video server.

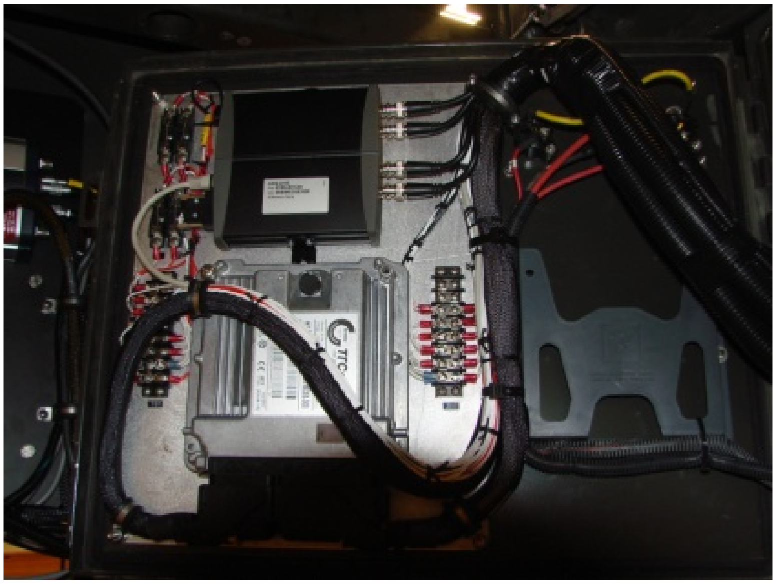

Figure 7. D-Box Systems Plate - TTC and Video Server

The roof systems plate (Figure 8) is mounted on top of the cab and includes a GPS module, pan/tilt/rotate camera, hi-level computer, Ethernet switch, and a radio system.

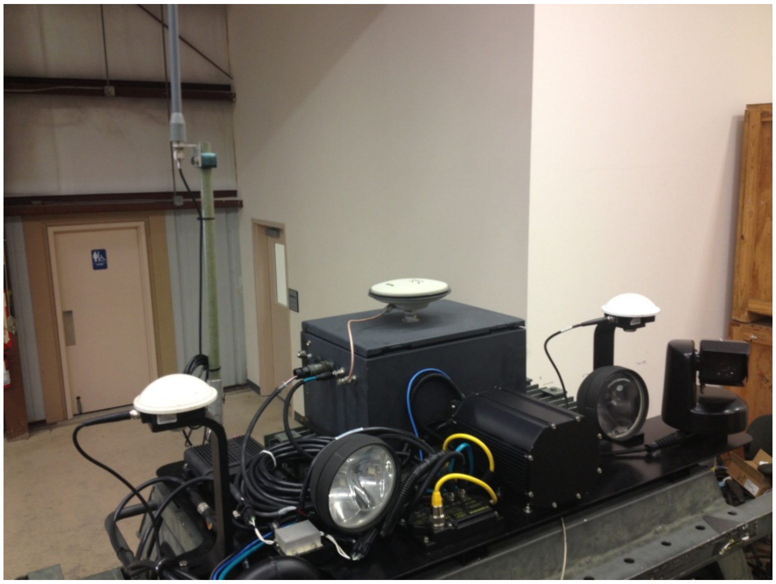

Figure 8. Roof Systems Plate

There is a fixed camera and a light detection and ranging (LIDAR) sensor in the front bumper (Figure 9) and another set in the rear bumper (Figure 10). The Robotics Team installed an additional 4 E-Stops throughout the loader.

Figure 9. Front Bumper LIDAR and Camera

Figure 10. Rear Bumper LIDAR and Camera

3.1.2. K-Loader Operation Modes

3.1.2.1. Manual and Tele-Remote Operation

The K-Loader can be manually driven/operated or remotely controlled, selectable by a switch on the outside of the vehicle next to the main panel (Figure 5). Manual control enables standard vehicle use using an on-board operator. Remote control allows robotic operation through the OCS at the operations center.

Figure 11 below shows a diagram with the modules needed to operate the K-Loader in the tele-remote mode. Everything inside the dashed box is installed on the vehicle. At the lowest level of integration RXQ installed a TTC system that ties directly into relays and switches of the vehicle and provides a CAN message interface for the VIM to communicate. From this level up, the modules communicate in Joint Architecture for Unmanned Systems (JAUS) messaging architecture. JAUS is a common language enabling internal and external communication between unmanned systems. It incorporates a component-based, message-passing architecture specifying data formats that promote stability of capabilities by projecting anticipated requirements as well as those currently needed. JAUS is open, scalable, and responsive to the unmanned systems communities' needs. The goal of JAUS is interoperability with an emphasis on the logical communications between heterogeneous computing systems used for unmanned systems command and control.

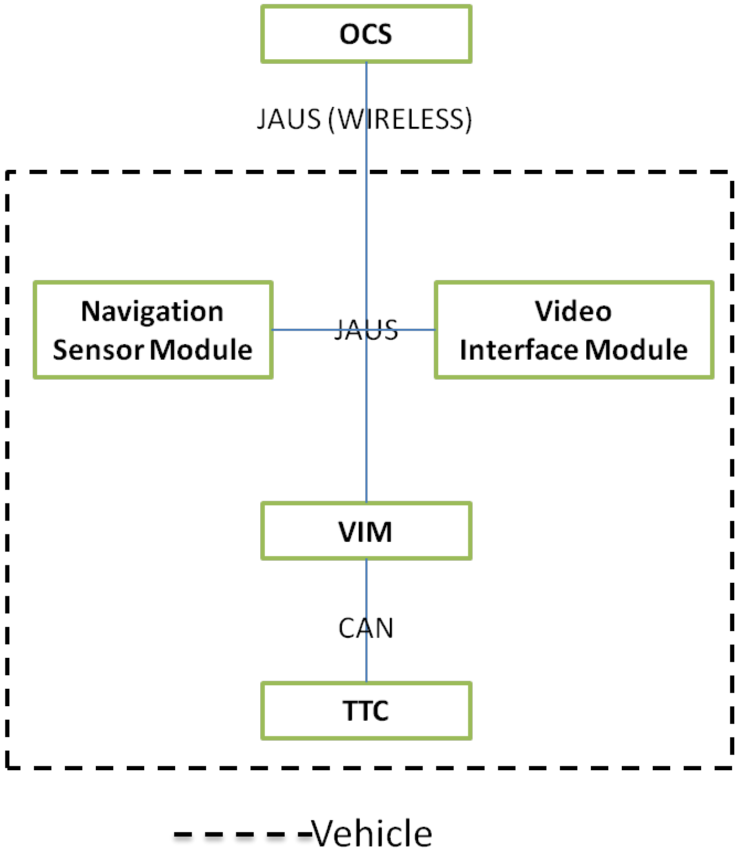

Figure 11. Manual and Tele-Remote Operation Diagram

3.1.2.2. Semi-Autonomous Operation

Figure 12 below shows a diagram with modules needed to operate the K-Loader in the semi-autonomous mode. Everything inside the dashed box is installed on the vehicle. This mode is also called waypoint driving mode because the vehicle can drive on a determined path using waypoints. It needs other components like the NSM, the VCM, the VIM, and the object detection sensors to navigate safely from one location to the other. After the routes are determined by the operator, the system doesn't require anymore commands from the operator, other than supervision if something goes wrong. The object detection sensors will stop the vehicle if any object is within 5 meters of its path.

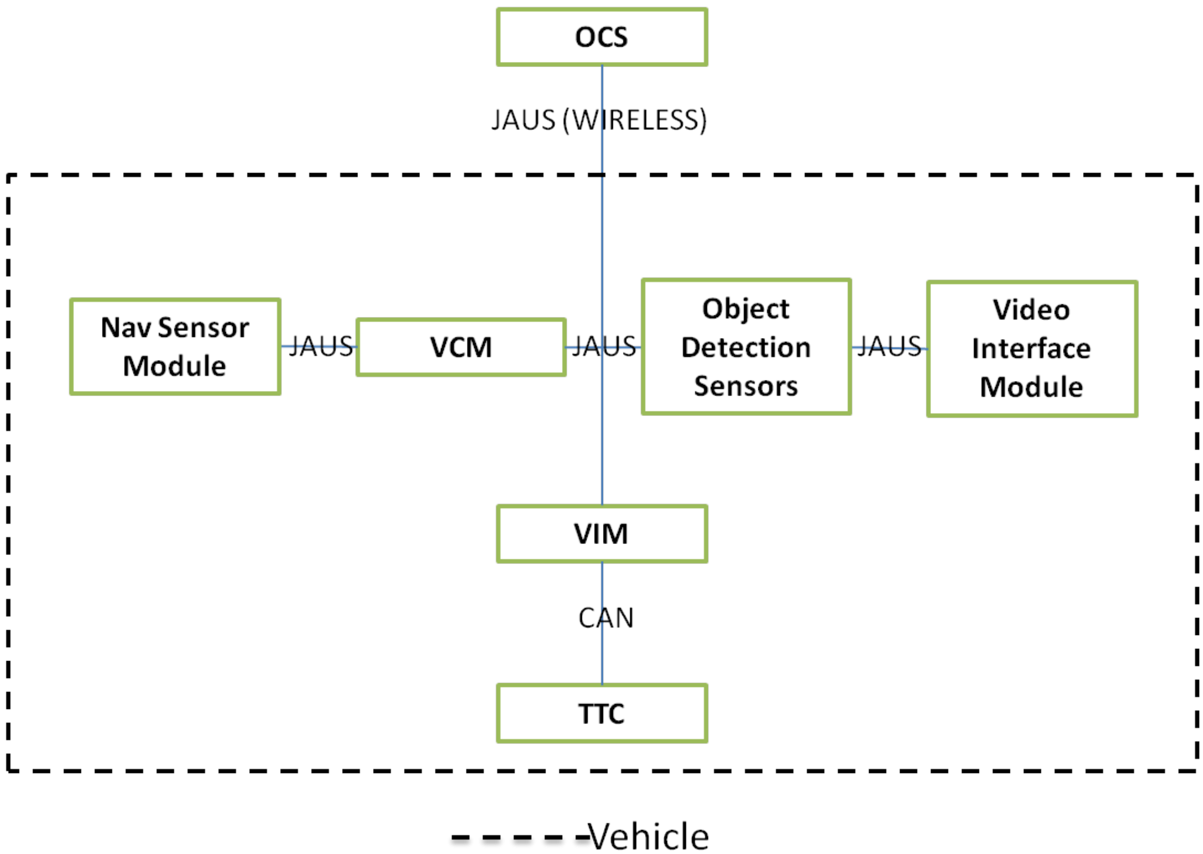

Figure 12. Semi-Autonomous Operation Diagram

3.1.3. Operations

3.1.3.1. Operator Control Station

The OCS can be located anywhere, it can be in an office, outside, or a vehicle as shown in Figure 13. For the demonstration AFRL/RXQ used the Robotic Team's command vehicle with equipped power, monitors, cameras, antennas, and climate control. This command vehicle provided an office like environment to operate the loader out at the remote site of Silver Flag Exercise Site. The radio antenna and GPS base station antenna were located on the roof. The main operator sat on the passenger side of the vehicle as shown in Figure 14. A larger monitor was used instead of the computer screen for ease of operation. The person on the operator's side is a safety officer (Figure 14) in charge of keeping an eye on the status of all the sensors and computers onboard the K-Loader. The safety officer will not be needed in an operational environment but he was used because this is a prototype. The loadmaster(s) or the "Port Dawg" in charge will have a remote kill switch, where if he notices anything wrong with the operation he/she can disable the K-Loader.

Figure 13. Operator Control Station

Figure 14. Main Operator (Right) and Safety Officer (Left)

3.1.3.2. Operator Control Unit

A GETAC ruggedized computer with an additional monitor serves as the host computer for the OCU (Figure 15) at the OCS (Figure 13). A Logitech gamepad controller and a standard mouse were used to control the K-Loader through tele-remote operation or semi-autonomous waypoint driving mode.

Figure 15. Operator Control Unit

Figure 16 below shows a screenshot of the display used by the operator to control the K-Loader. The on-screen controller has all the switches, buttons, led, gauges, and displays that are on the K-Loader. On the top left it has the conveyor controls and the deck indicators. The Robotics Team added a digital read out of the height of the deck. On the middle left it has the front controls used to turn on/off the loader, exterior lights, and transmission gear selection. The bottom left display is the vehicle selection list. The operator can select which vehicle they want to operate, if there is more than one vehicle. The center image displays the view from the cameras. By a single click the operator can switch from the front, rear, or roof camera. To facilitate tele-remote docking of the K-Loader to the loading ramp, AFRL/RXQ overlaid a crosshair on the video feed. Below the camera display there is a display of all the gauges like speed, rpm, steering angle, water temp, fuel, oil temp, and battery voltage. In this same box, there are three buttons to select the operation mode (Tele-operation, Waypoint Driving, and Deck Controls). At center bottom of the screen there are two tools for waypoint driving route setup. The right side of the display shows the map of the operation area of the K-Loader. This is an interactive map where the routes are planned and changed using the waypoint driver tools. The K-Loader is shown by the red rectangle and the routes are shown in different colors. These routes are determined and stored at an earlier time but they can be changed as the vehicle is traveling a route.

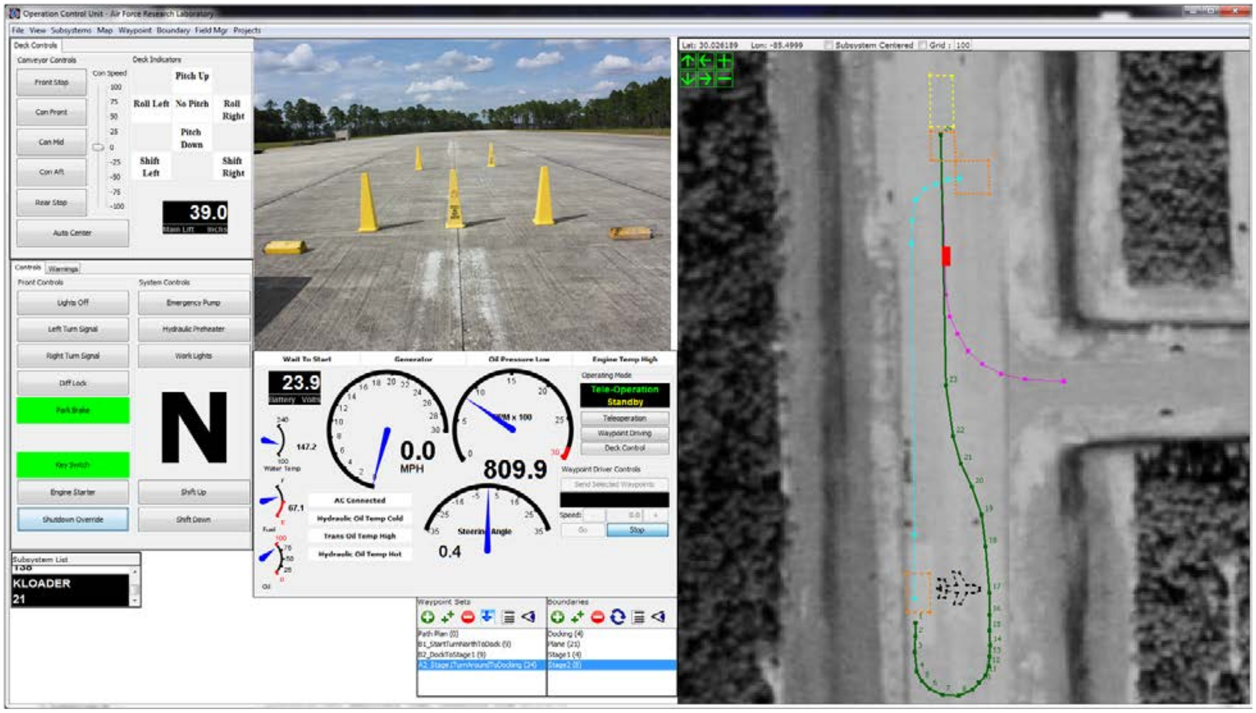

Figure 16. Operator Control Unit Screen Shot

3.1.3.3. Communication Flowchart

The OCU laptop computer was connected to the OCS's network through wired Ethernet. On the same network was a NovAtel GPS base station system that sends differential GPS corrections to the vehicle. An Esteem 2.4GHz wireless radio provided bi-directional communication from the OCS to the vehicle. See Figure 17 below.

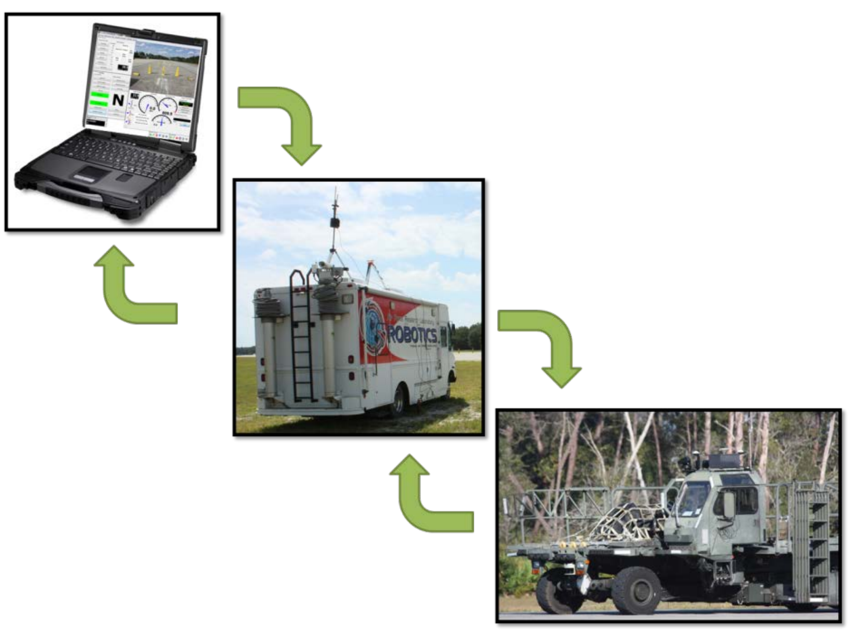

Figure 17. Communication Flowchart

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3.2. Technologies

This effort required a fusion of technology to provide automated controls for the K-Loader. The platform is a Halvorsen 25K Aircraft Loader (Figure 18) and the standard pallets used by the military are the HCU-6/E 463L Master Pallet (Figure 19). The major sensors used for this effort were: obstacle detection sensors, navigation system, cameras, potentiometers, electric-hydraulic steering valve, and software to control all the sensors and systems.

3.2.1. Platforms

Table 1. Halvorsen 25K Aircraft Loader Specifications [2]

Characteristic	Description
Model Type	Self propelled, air transportable, aircraft loading/unloading vehicle
Gross Weight	31,350 lb. (wet)
Width (operation)	170 in
Width (air transport)	109 in
Length	29.5 ft
Deck Height	39 in to 225 in
Ground Clearance	5 in
Max Speed	17 mph
Capacity (Payload)	25,000 lb.
Rolling Stock	15,000 lb. per axle
Turning Diameter	50 ft
Fuel	23.75 gal (DFA, DF1, DF2, JP5, JP8)
Electrical	24 vdc

Figure 18. Halvorsen 25K Aircraft Loader

Table 2. HCU-6/E or 463L Master Pallet Specifications [3]

Characteristic	Description
Model Type	Aluminum standardized cargo pallet
Composition	Corrosion-resistant aluminum with a soft wood or fiberglass core and is framed on all sides by aluminum rails
Weight	290 lb. (empty), 355 lb. (complete set of nets)
Width	108 in (104 in Usable)
Length	88 in (84 in Usable)
Thickness	2 ¼ in
Max Load Capacity	10,000 lb.
Max Load per sq inch	250 lb.
Turning Diameter	50 ft

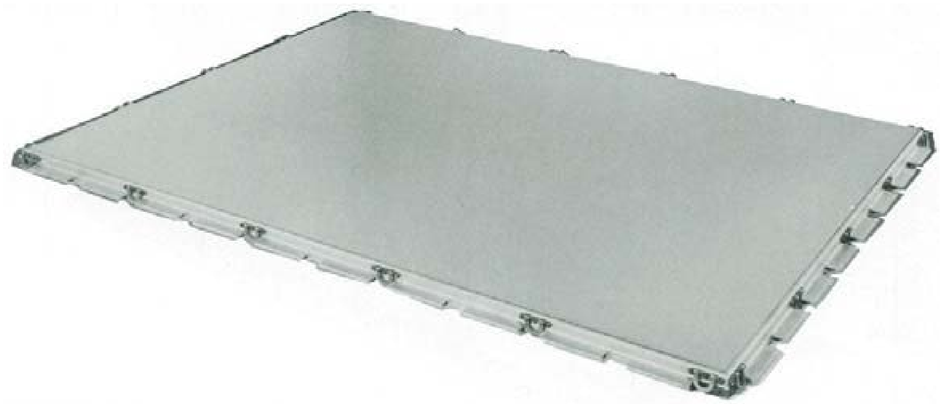

Figure 19. 463L Master Pallet

3.2.2. Sensors

There are several different sensors and combination of sensors that were used to detect, map, and guide the automated K-loader system. Sensors that were used include but are not limited to LIDAR sensors, navigation system, potentiometers, electric-hydraulic steering valve, software to control all the sensors and systems, and EO and IR cameras combined with various vision algorithms.

3.2.2.1. LIDAR

LIDAR sensors are commonly used in robotics to build maps of the unknown local area. These maps are then typically used in path planning and obstacle avoidance. LIDAR was used in this effort to map out the area surrounding the loader and to detect any stationary and moving objects of interest. In selecting a LIDAR there are tradeoffs that must be considered such as cost, accuracy, precision, range, and field of view. For this project we used the SICK LMS 291 (Figure 20). Two SICK LIDAR units (approximately $6,000 each) were borrowed from other projects to save money on the effort. The maximum range it can detect is 80 meters with an error of about 10mm, but the closer the object the better resolution. It can scan at a rate of 75 Hz with a field of view of 180° and a 0.25° angular resolution. The SICK LMS 291 relies on a spinning mirror and laser diode to perform time-of-flight distance calculations.

Figure 20. SICK LMS 291 LIDAR

SICK LMS291 Features [4]

- Dimensions: 18.5 × 15.6 × 21.0 cm
- Weight: 4.5 kg
- Power: 24 VDC, 20 Watts
- 180° coverage
- Indoor applications
- High measurement resolution (10 mm resolution)
- Contact-free measurement
- Target objects require no reflectors or markings
- High scanning frequency (up to 75 Hz)
- Transfer of measurement data in real time
- Active system, no illumination of target objects necessary
- Measurements possible over long distance (up to 80 m)
- Compact device construction
- Three internally programmable monitoring fields assigned to three switching outputs

3.2.2.2. Navigation System

For this effort, a combination GPS and IMU was required to provide position information at certain accuracy and update rate. RXQ used a NovAtel's SPAN GPS and IMU system (Figure 21). SPAN provides continuous 3D position, velocity and attitude determination even when GPS satellite reception may be compromised. It delivers up to one centimeter accuracy.

Figure 21: Navigation Sensor Module

NovAtel's SPAN GPS and IMU System [5]

Benefits

- Single enclosure SPAN-CPT™ GPS/INS system ideal for size constrained applications
- Provides continuous stable positioning and attitude even during brief periods when satellite signals are blocked
- Import/export issues are minimized

Features

- 100 Hz raw data and solution
- Wheel sensor input for ground applications
- Optional dual antenna

3.2.2.3. Cameras

There are two fixed cameras, one in the front bumper and another one in the rear bumper of the K-Loader. These are wide dynamic range infrared (IR) security cameras made by KT&C and it features high resolution with 18 IR light emitting diode (LEDs) for powerful night vision. The cameras utilize true mechanical day night and have advanced digital spread spectrum (DSS) technology for ultimate low light performance (Figure 22).

Figure 22: KT&C IR Optical Camera

Model: KPC-N600N [6]

- 1/3 Sony Vertical Double Density CCD
- Mechanical Day Night
- 480tvl high resolution
- 18 IR LEDs for 80 ft+ Night Vision
- 2.8-11 mm Vari-focal DC Auto Iris
- Electronic Sensitivity Up, DSS
- 12 VDC

Another camera was added to the roof plate of the K-Loader to get a 360 deg view from the top. The camera used is an RVision SEE HP pan/tilt/zoom optical camera (Figure 23).

RVision SEE HP Pan/Tilt/Zoom Optical Camera Features[7]

- 26x optical camera
- Image stabilization
- Auto focus
- Tilt Range 240°
- Pan Speed 120°/s
- Tilt Speed 120°/s
- Pan/Tilt Encoder Resolution 0.01°
- Weight 8.6 lbs
- Housing Material Cast Aluminum
- Voltage 12-30 VDC

Operating Temperature -40°C to +70°C

Figure 23: RVision SEE HP Pan/Tilt/Zoom Optical Camera

3.2.2.4. Potentiometers

It was important to understand the orientation of the K-Loader and the height of the deck. To get digital readouts of the K-Loader's orientation, linear potentiometers (POTs) were added to all the hydraulic cylinders (Figure 24). The POTs where then programmed and calibrated to get the correct values for each orientation of the deck, like the height of the deck.

“The UniMeasure JX-PA series linear position transducer with analog output is primarily for use in moderate duty applications in wet or dry environments. The plastic bodied device is ideal for high-volume original equipment manufacturer (OEM) situations where cost is a major consideration and in applications where small size or low weight is of paramount importance. Models are available in 13 measurement ranges with the shortest range of 2 in (50 mm) and the longest range of 80 in (2000 mm).” [8]

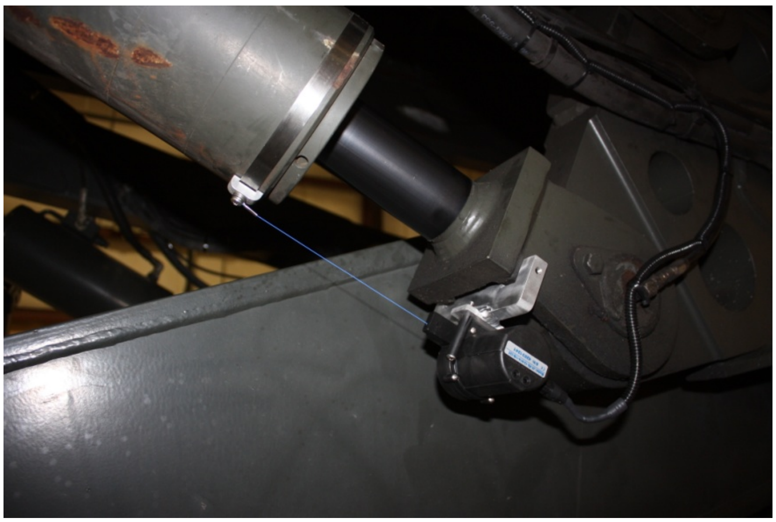

Figure 24. Linear Potentiometer

UniMeasure JX-PA Linear Potentiometer Features [8]

- Low Cost
- NEMA 4 (IP-65) Capable
- Thermoplastic Housing
- Analog or Digital Output
- Connector/Cable Connection
- Integral Dust Wiper
- Compact Size
- 80 in (2000 mm) Max Range
- 13 Measurement Ranges
- Linearity
- 2 in, 2.8 in, 3.8 in, 4.7 in ranges ±1.0% Full Scale
- 10 in to 25 in ranges ±0.5% Full Scale
- 30 in to 80 in ranges ±0.25% Full Scale

3.2.2.5. Electrohydraulic In-line Steering Valve

There are different ways to actuate steering in a vehicle. One of those solutions is to attach a steering ring to the steering wheel that has a motor to do the steering. This approach presents both calibration and installation issues. An electrohydraulic in-line steering valve was used for this project. This electric valve was a replacement for the stock valve (Figure 25) that is on the K-Loader. A robust, single piece casting also eliminates potential leak paths, while the compact construction of the steering unit saves space compared to other systems. The electrohydraulic valve (Figure 26) was a direct bolt-on replacement with the exception of the size. It sticks out about 5 in towards the front, see Figure 26. The valve installed was an OSPE LS Electrohydraulic In-line Steering Valve made by Sauer Danfoss. It was ordered with the optional embedded PVED-CL steering controller and SASA sensor for variable steering ratio (Quick Steering) and closed loop control.

Electrohydraulic In-line Steering Valve Features [9]

- Model: OSPE
- Part Number: 11113002
- Steering Type: LS (Load Sensing)
- Pressure: 210 psi
- Displacement: 100-500 cm^3/rev

Figure 25. Manufacturers Hydraulic Valve (Original)

Figure 26. Electrohydraulic In-line Steering Valve

3.2.3. Software

3.2.3.1. Architecture

Similar to the hardware modules described in previous sections, the software developed and used for the K-Loader was done in modules connected through an Ethernet network. The modular nature allows each piece of software to be independently developed and tested. Also, the software developed was leveraged off field-tested unmanned ground vehicle software and tailored for the K-Loader. The message protocol that enables this modularity is based on the JAUS standard (see description below).

The different software modules are segregated depending on the specific function they perform. There is a tight relationship between the software and the computer hardware it resides on. For example, the Vehicle Control Unit (VCU) software, which controls all the low-level functions and reads the vehicle feedback, resides on the VIM computer. However, the VCM computer runs three different software modules (Global Waypoint Driver (GWD), Range Sensor, and Visual Sensor). The selection of the computer on which a specific program runs on depends on factors such as the physical connections to the sensors, and the amount of computing power required.

3.2.3.2. Vehicle Control Unit

The VCU code's primary purpose is to serve as the JAUS bridge between the low-level TT Control and the higher level software. Driving commands from either the OCU or the Global Waypoint Driver are translated to vehicle throttle, steering and brake commands. Also, all the vehicle status, feedback, read in and repacked into JAUS messages. For safety reasons, vehicle control was separated into a driving mode and a deck mode. In deck mode, all the loader deck specific functions are available, while in drive mode they are not. It was designed this way so that cargo wouldn't accidently be moved while remotely driven.

3.2.3.3. Position System (POS)

Embedded on the navigation sensor module, the POS code communicates directly with the NovAtel SPAN system. It provides high accuracy pose (position, velocity and attitude) data at high rates to whichever software component requests it. The POS typically serves pose data to the OCU, GWD, and the range sensor. The POS uses GPS corrections data sent by the GPS base station and sends it to the NovAtel SPAN via RS-232 serial port.

3.2.3.4. Visual Sensor

The visual sensor code takes in streaming video data from an Axis video server and packs it as JAUS video data. Control of selection of which camera to view is also part of the visual sensor code. The Visual Sensor translates OCU joystick commands to pan/tilt control of the R-Vision camera. Video data sent back to the OCU has a 320 × 240 pixel resolution and a 15 Hz frame rate.

3.2.3.5. Range Sensor

Used in obstacle detection and avoidance, the range sensor code processes SICK LIDAR data from both the front and rear units. The detected object data is then outputted as a list of polar points (range and bearing information) with reference to the sensor units. The VCU and the GWD use the object data during navigation. Depending on whether the vehicle is travelling in

forward or reverse, the object data influences how the VCU and the GWD adjust the speed of travel.

3.2.3.6. Global Waypoint Driver

The global waypoint driver's function is to take in waypoints (in geodetic coordinates) sent from the OCU and calculate the vehicle linear velocity and rotational velocity commands necessary to navigate to these waypoints. The GWD sends these commands down to the VCU which in turn converts them into throttle, steering and brake commands. The GWD uses object data from the Range Sensor to adjust its linear speed.

3.2.3.7. JAUS Operator Control Unit

The JAUS OCU software provides the human operator's interface to the vehicle (Section 3.1.3). The OCU code uses JAUS messages to communicate with all the software components of the vehicle. Using data from input devices (joystick, mouse and keyboard), the OCU sends command messages for driving control, deck control, and camera control. Service connections are set-up for essential vehicle feedback data. The OCU graphical user interface utilizes resizable and movable windows to display specific information (e.g. video, map, gauges). As a safety feature, the OCU driving commands serve as a heartbeat to the vehicle. In the event that the vehicle does not receive the OCU heartbeat within 1.5 seconds, the vehicle goes into a stand-by state, where the vehicle comes to a complete stop by applying the brakes.

3.2.3.8. JAUS

JAUS is a common language enabling internal and external communication between unmanned systems. It incorporates a component-based, message-passing architecture specifying data formats that promote stability of capabilities by projecting anticipated requirements as well as those currently needed. JAUS is open, scalable, and responsive to the unmanned systems communities' needs. The goal of JAUS is interoperability with an emphasis on the logical communications between heterogeneous computing systems used for unmanned systems command and control.

4. RESULTS AND DISCUSSION

4.1. Testing

AFRL/RXQ's approach for this project was to divide the testing into three major tests. The three test are: a Low-Level systems test (Test 1), a Tele-Remote Operation systems test (Test 2), and a Waypoint Driver systems test (Test 3). The integration of the systems where in this order and each system had to be tested and verified that it was working correctly before the next system was integrated.

Test 1 assessed all of the K-Loader functions via a hard wired computer next to the loader. This was a bench test to insure all the electrical connections and electrical commands were going to the relay and switch boxes of the K-Loader. There was no driving performed during this test, since the electrohydraulic steering valve was backordered. This test was performed outside of building 9725 (Figure 27).

Figure 27. OCU Setup Outside of Building 9725

Test 2 assessed all of the K-Loader capabilities via tele-remote operation using the south road of the 9700 compound (Figure 28). Tele-Remote Operation included the driving of the K-Loader as well as all the deck functions. The team setup antennas and an OCU outside of building 9725 and went through a checklist of all K-Loader operational functions.

Test 3 assessed the waypoint driver system and obstacle avoidance capabilities using the south road of the 9700 compound (Figure 28) and the Silver Flag Exercise Site at Tyndall AFB (Figure 29). More details on test locations will be described later in the report. Test 3 at the 9700

Figure 28. AFRL/RXQ 9700 Test Site

compound included initial waypoint driving testing, which required a lot of positioning and vehicle control tuning. Due to the small roads, calibration of turning was not performed at this location. AFRL/RXQ coordinated with Tyndall's 823rd Red Horse Squadron to use Silver Flag's airfield for further waypoint driver systems testing. At this location AFRL/RXQ was able to do full operational runs that included waypoint guided turns and obstacle detection. The following parameters were successfully demonstrated.

4.1.1. Overall Parameters

- Drive (waypoint) from operation center to loading ramp (simulated by trailer)
- Dock and receive a pallet from loading ramp (tele-remote mode)
- Drive (waypoint) from loading dock to staging area next to aircraft
- Drive (waypoint) from staging area to operation center
- Reduce speed of vehicle when object is present within 49.2 ft (15.0 m)
- Constant deceleration from 49.2 ft to 16.4 ft (15.0 m to 5.0 m)
- In Waypoint Driver mode, halt vehicle when object is within 16.4 ft (5.0 m)
- In Tele-Remote mode, halt vehicle when object is within 1.6 ft (0.5 m)
- Tele-Remote Brake Sequence
    - 16.4 ft to 8.2 ft (5.0 m to 2.5 m), set throttle to idle
    - 8.2 ft to 4.9 ft (2.5 m to 1.5 m), apply 40% braking effort
    - 4.9 ft to 2.3 ft (1.5 m to 0.7 m), apply 45% braking effort
    - 2.3 ft (0.7 m) or less, apply 100% braking effort
- Demonstrate vehicle's main functions (tele-remote mode)
    - Lift, pitch, roll, shift, etc.

4.1.2. Driving Parameters

The threshold and objective values of the parameters tested below (Table 3) were determined based on AFRL/RXQ's extensive repository of automated systems experience. All the tests yielded excellent results and all the actual values where significantly below the threshold values. All the objectives were met with the exception of the maximum distance from the path while performing turns. Performing turns with such a large vehicle is difficult even when driven manually with an operator in the cab. This parameter is more dependent on the vehicle than the systems RXQ installed on the K-Loader, but the measurement was still important for the evaluation.

Table 3. Driving and Safety Parameters

Parameters	Threshold	Objective	Actual
Max Dist from Path (Straight)	4.5 ft (1.4 m)	3.3ft (1.0 m)	1.6 ft (0.5 m)
Max Dist from Path (Turns)	9.8 ft (3.0 m)	6.6ft (2.0 m)	6.8 ft (2.1 m)
Max Position Error at Final Waypoint	9.8 ft (3.0 m)	6.6ft (2.0 m)	2.0 ft (0.6 m)
LIDAR Safety Distance (Tele-Remote Mode)	0.9 ft (0.3 m)	1.6ft (0.5 m)	1.6±0.7ft (0.5±0.2 m)
LIDAR Safety Distance (Waypoint Mode)	9.8 ft (3.0 m)	16.4 ft (5.0 m)	16.4±1.6 ft (5.0±0.5 m)
2.2mph (1.0m/s) to Zero Stopping Distance	6.6 ft (2.0 m)	3.3 ft (1.0 m)	2.0±0.3 ft (0.6±0.1 m)
Speed Error	30%	20%	± 15%

All the actual values in the table below are highlighted in green because they were significantly below the threshold, with the exception of the LIDAR safety distance in tele-remote mode. This was highlighted yellow because in some instances it stopped right at the threshold. This was not a major concern because in tele-remote mode the operator was very carefully driving the K-Loader and has total control to stop the vehicle if it would pass the threshold. When docking to a loading ramp the goal was to get as close as possible and this was demonstrated. In phase II, very precise sensors will be installed for docking, where the K-Loader will be within millimeters from contact.

4.2. Test Sites

9700 Test Site was used for Test 1, 2, and 3. Figure 28 shows that the south-end of the 9700 compound loop that was used, with road closures shown by the red-crossed circles. These closures allowed traffic to access all the buildings during normal work hours. The K-Loader system drove in a straight line from east to west and used the short section heading north to do a three-point-turn when necessary. The east to west road is about 1,300 ft long × 18 ft wide and the north to south section is about 300 ft long × 48 ft wide.

Silver Flag Test Site was used for Test 3 and the final demonstration. Figure 29 below shows the north end of the runway and the section of the taxiway that was used. Objects were placed throughout the test area to assess the obstacle detection system. The north to south section of the runway is about 2,000 ft long × 150 ft wide. The taxiway to the right, oriented from west to east, is about 1,000 ft long × 75 ft wide. This was a safe location for this test because of the open space available for testing and very few obstacles off the side of the runway.

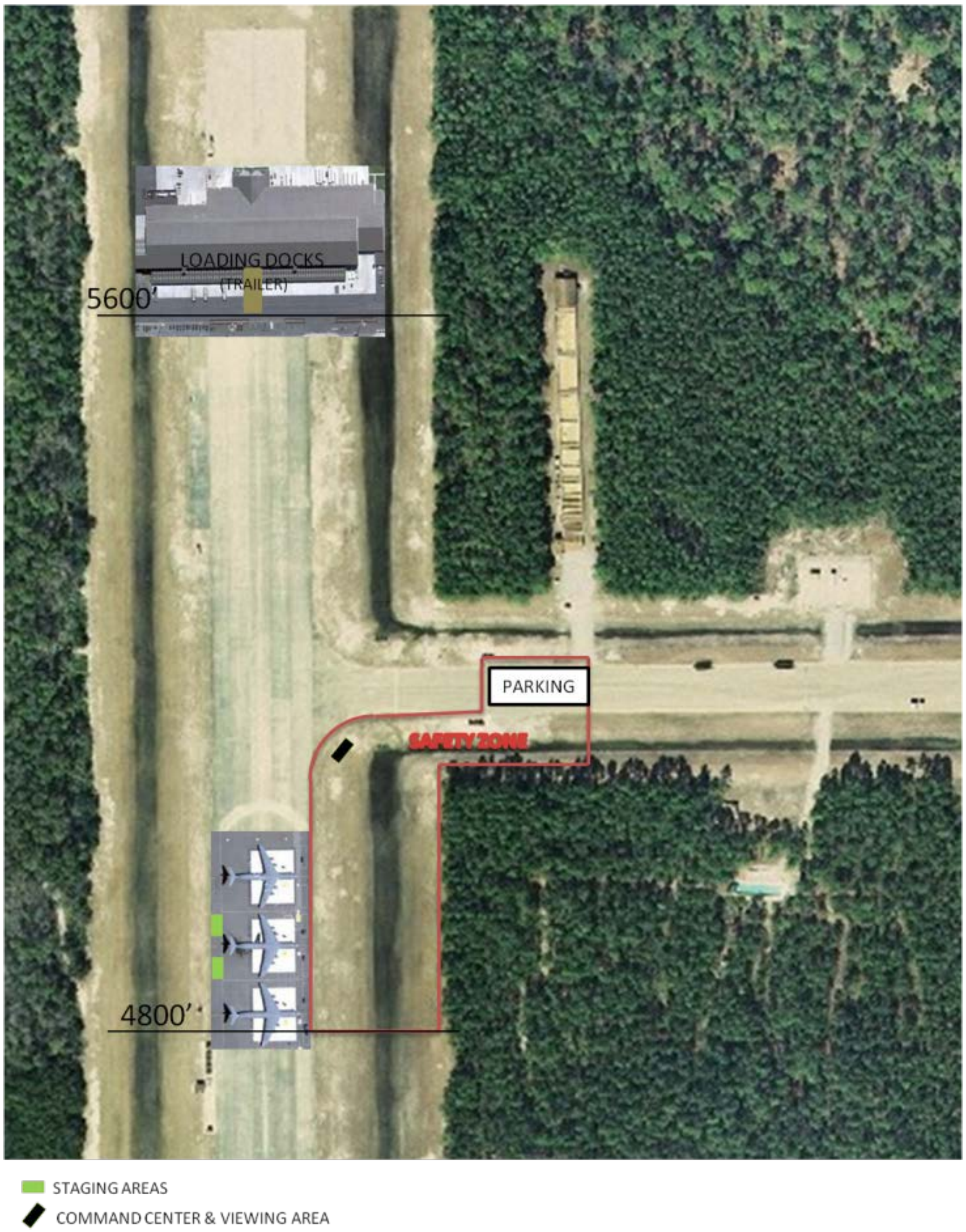

Figure 29. Silver Flag Test Site

4.3. Final Demonstration

The Robotic K-Loader Demonstration was hosted by AFRL/RXQ on 25 October 2012 at Silver Flag Exercise Site Tyndall AFB, Florida. The demonstration was able to show the automated capabilities of the system in an aerial port representative environment, which put the system at a technology readiness level 5. The purpose of this demonstration was to bring together personnel that are involved with current and future cargo handling equipment and discuss the future of this technology. AFRL/RXQ hosted guests from the Army's Robotic Systems Joint Program Office (RS JPO), the Air Force's Life Cycle Management Center / Support Equip & Vehicles Directorate, an Operations Manager from the 437th Aerial Port Squadron, Charleston AFB, and Air Force Civil Engineering Center (AFCEC).

The Silver Flag site was setup to represent an aerial port layout at an AFB like Charleston AFB. AFRL/RXQ used a flatbed trailer with roller on the end to simulate a loading ramp (Figure 30). The aircraft was marked on the runway by an "X" painted on the runway and marked by cones on each corner (Figure 31). The safe aircraft staging area was behind the aircraft marked by four orange cones (Figure 31). There was a distance of 720 ft from the loading ramp to the aircraft staging area.

Figure 30. Trailer with Rollers used as Loading Ramp

Figure 31. Simulated Aircraft and Aircraft Staging Area

Figure 32 below shows the scenario setup and the routes that were programmed into the waypoint driver. The numbers correspond with the scenario steps described later in this section. The K-Loader travelled from 1 to 2 using the purple path, 2 to 3 using the light blue path, and 3 to 4 using the green path. Step 5 was tele-remotely operated to the center of the runway to demonstrate the K-Loader functions in tele-remote mode.

Demonstration Scenario

1) Starting location
    a. K-Loader can be at any location in the tarmac (Figure 33)
    b. Remote start with OCU
    c. Load waypoints
    d. Command Go to Loading Ramp

2) Loading Ramp (Load pallet)
    a. Stop 5 m from ramp
    b. Switch to tele-remote operation mode
    c. Dock and load pallet onto K-Loader (Figure 34)
    d. Command GO to Aircraft Staging Area

3) Aircraft Staging Area
    a. Stop within the staging area (Figure 35)
    b. Wait for loadmaster to command load/unload of aircraft (Driver in cab operation)
    c. Load and Unload aircraft (Simulated)
    d. Command Go to Loading Ramp

4) Loading Ramp (Unload pallet)
    a. Stop 5 m from ramp
    b. Switch to tele-remote operation mode
    c. Dock and unload pallet from K-Loader (Figure 36)

   d. Drive to demo area (center of runway)

5) Demo area (In front of operator control station)
   a. ½ lift
   b. Pitch/Roll/Shift/Center all (Figure 37)
   c. Full lift
   d. Full down

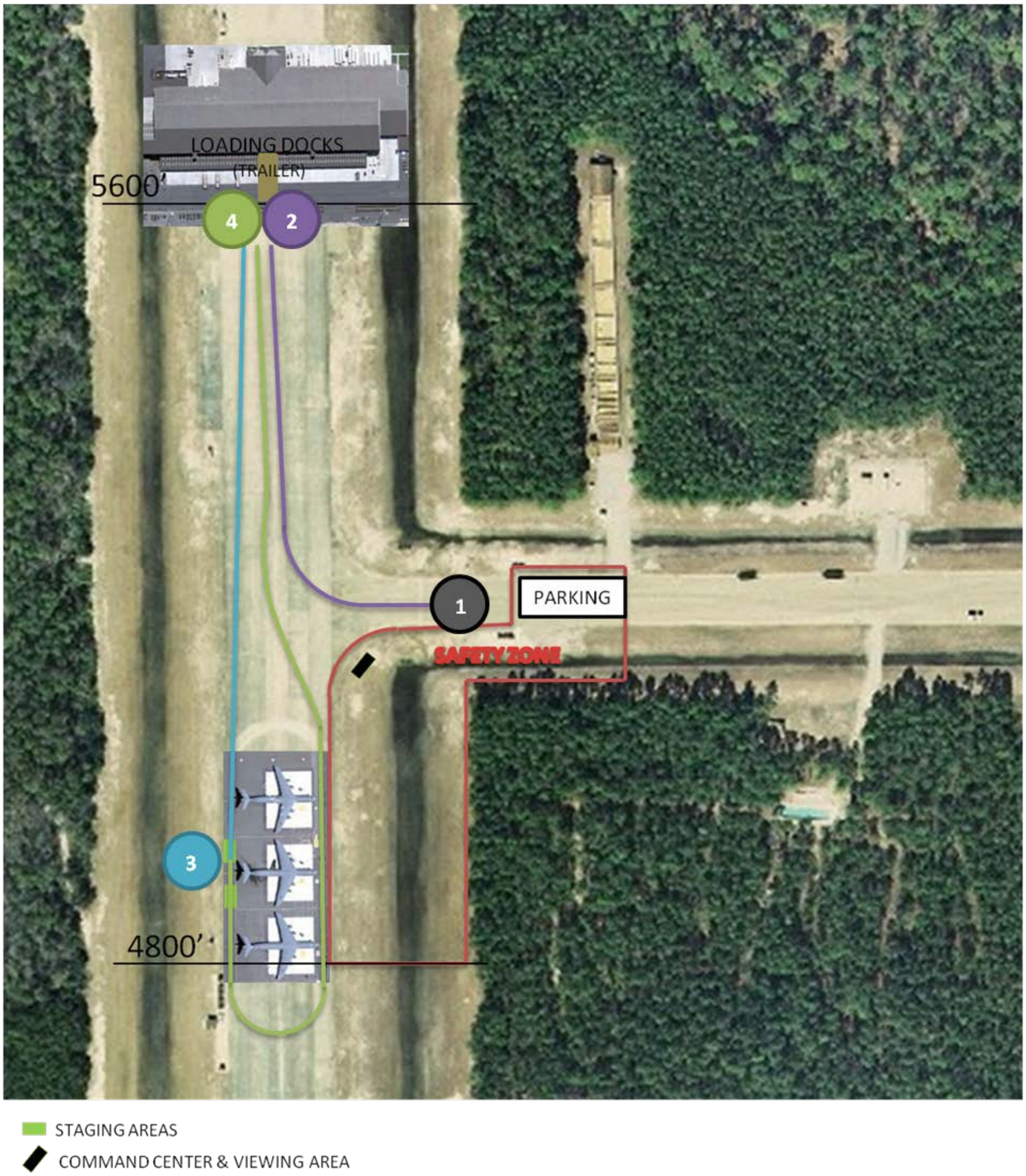

Figure 32. Scenario Setup and Waypoint Routes

Figure 33: K-Loader at Starting Location

Figure 34. K-Loader at Loading Ramp

Figure 35. K-Loader at Aircraft Staging Area

Figure 36. K-Loader at Loading Ramp (Unload)


Figure 37. K-Loader Tele-Remote Forward Pitch

5. CONCLUSIONS

Automated Cargo Handling is one of AMC's critical capability gaps. For this effort, AFRL/RXQ personnel designed and implemented a robotic control package for autonomous driving of the 25K Halvorsen Loader system that successfully met that need. On 25 October 2012 AFRL/RXQ conducted an operational demonstration at the Tyndall AFB, FL Silver Flag exercise site, which met all of the Phase I technology objectives.

This effort demonstrated that fielded automated cargo handling systems can be affordably modified for tele-operated and autonomous operations. The robotic system implemented on the 25K Halvorsen Loader was based on proven technologies with a long history of reliable operations on various Air Force robotics systems. This effort has proven that automated cargo handling technologies are mature enough to be considered for daily aerial port operations if the mission need dictates their use. This demonstration concluded the funded work for this effort, but the technology is ready to advance to the next development phase if sponsorship is available.

6. RECOMMENDATIONS

AFRL/RXQ recommends three different options for the future of the automated K-Loader effort:

- The first option is to keep the automated K-Loader system at Tyndall AFB and request funding for the completion of Phases 2–4. Terminal interface automation tasks, Aircraft interface automation tasks, and Experimental demonstration in an operationally representative environment.
- The second option is to deliver the automated K-Loader system to a base, where it can be used in exercise scenarios to evaluate the current automation system and provide feedback.
- The third option is to remove the automation kit and return the K-Loader to its original condition. The automation kit can be packaged and stowed for future use on another system.

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LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

°	degrees
°/s	degrees per second
°C	degrees Celsius
°F	degrees Fahrenheit
AFB	Air Force Base
AFCEC	Air Force Civil Engineering Center
AFRL	Air Force Research Laboratory
AFRL/RXQ	Air Force Research Laboratory, Airbase Technologies Division
AMC	Air Mobility Command
CAN	controller area network
cm	centimeter
cm^3/rev	cubic centimeter per revolution
D-Box	distribution box
DSS	digital spread spectrum
E-Stop	emergency-stop
ft	feet
ft-lb	feet pound (torque)
gal	gallon
GPS	Global Positioning System
GWD	Global Waypoint Driver
HQ	Headquarters
Hz	hertz (frequency unit)
in	inch
I/O	input/output
IMU	inertial measurement unit
IR	infrared
JAUS	Joint Architecture for Unmanned Systems
kg	kilogram
K-Loader	cargo loader
lb	pound
LED	light emitting diode
LIDAR	light detection and ranging
MAF	Mobility Air Force
MHE	materials handling equipment
m	meter
mm	millimeter
mph	miles per hour
NSM	navigation sensor module
OCS	operator control station
OCU	operator control unit
OEM	original equipment manufacturer
PDM	power distribution module
POS	position system
POT	linear potentiometer
psi	pounds per square inch

qt	quarts
TTC	TT-Controller
rpm	revolutions per minute
RS JPO	Robotic Systems Joint Program Office
RXQ	Airbase Technologies Division
USAF	United States Air Force
VDC	voltage direct current
VCM	vehicle command module
VCU	vehicle control unit
VIM	vehicle interface module
watt	derived unit of power in the International System of Units